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HDTV BROADCASTING BY SATELLITE:

Some factors which affect the link budget

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Summary

The Report investigates the power required to be transmitted by a satellite broadcasting high-definition television (HDTV). A study is made of the way the various parameters which make up the link budget can be fine-tuned to give the most acceptable trade-off between satellite transmitter power and signal quality.

It is concluded that, in the foreseeable future, frequencies up to at least 23 GHz may be considered for HDTV broadcasting by satellite.

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HDTV BROADCASTING BY SATELLITE: SOME FACTORS WHICH AFFECT THE LINK BUDGET

J.H. Stott, M.A. and P. Shelswell, M.A., C. Eng., M.I.E.E.

1. INTRODUCTION

There is currently much debate about the broadcasting by satellite of high definition television (HDTV)[1,2].

The CCIR is considering this question and in particular is looking at the problem of finding a single worldwide frequency allocation for HDTV[3]. At present 22.5 GHz to 23 GHz is allocated to ITU Regions 2 and 3 but not Region 1 (which includes Europe)[4]. There is a band at 42 GHz allocated worldwide. However this is not suitable for HDTV in the near future because of the lack of development of the technology required and the excessive attenuation caused by rain at these frequencies. The problems caused by rain attenuation increase as the frequency of operation increases. However, it must be questioned whether or not the 22.5 GHz band is suitable for HDTV and for ITU Region 1, at least, whether some other frequency band would be more suitable.

When considering which band is suitable, it has to be shown that

a) adequate signal quality is provided for a reasonably high percentage of the time

b) the satellite is not required to radiate at power levels that are higher than are likely to be achieved over a reasonable time-scale.

and c) that adequate sharing arrangements with other services can be achieved.

The latter factor will be the subject of discussion once technically feasible frequencies have been identified. Sharing is beyond the scope of this Report which concentrates on technically feasible frequencies.

The signal quality and the power of the satellite are related. The relationship is calculated using a link budget.

The Report explores the effects of changing the various parameters in the link budget and in particular the changes in the required satellite transmitter power. This power must be minimised to ensure that the proposals for HDTV are feasible, and to allow sharing of the band with other services as far as possible. Particular emphasis is placed on demonstrating that it is possible to radiate HDTV equitably to all countries at frequencies around 22.5 GHz.

2. METHOD OF WORKING

The method used in this Report was to take, as a starting point, an example link budget based on WARC-BS 1977[5] parameters and scaled as appropriate for HDTV.

The performance of this base-line system was first calculated.

The effect of varying the parameters was then examined, using the base-line budget as a reference. Because the effects are different for different geographical locations, examples of temperate and tropical target service areas were used.

After observing the effect of all the parameters, revised example systems were examined to show what improvement could be achieved over the base-line example.

In all the analyses, the necessary satellite transmitter power was calculated, and used as a measure of the suitability of any option. It is necessary to ensure that it is possible to broadcast at power levels which are expected to be achievable in the near future.

3. PARAMETERS CHOSEN FOR THE EXAMINATION

The link budget contains many parameters; those listed in Table 1 were chosen for examination. Alongside each parameter is an indication of the range of values which may be considered realistic. The value used in the base-line calculation is also tabulated.

Furthermore, it is premature to define the parameters of an HDTV broadcasting system, given that studies are now progressing rapidly on a wide range of techniques. However the range of values proposed is typical of those currently under discussion[6].

The parameters in italics are those for which there is a linear relationship between themselves and the transmit power required (for a given required value of carrier-to-noise ratio).

Table 1: List of link budget parameters

Parameter	Base-line value	Range of values
Operational frequency	22.5 GHz	10 to 30 GHz
Noise bandwidth	54 MHz	27 to 100 MHz
Required C/N	14 dB	10 to 20 dB
% time for service	0 to 99.99% year	0 to 99.99% year
Receiver		
Antenna Diameter	0.7 m	0.5 to 1 m
Aperture Efficiency	0.6	0.5 to 0.7
Noise Figure	4 dB	1 to 6 dB
Dissipative loss factor	1 dB	0.5 to 2 dB
Non-dissipative loss factor	1 dB	0.5 to 2 dB
Antenna noise temperature	as Fig. 1	a function of slant path attenuation
Relative longitude	as at WARC 77	0 to 60 degrees
Height above sea level	0 m	0 to 1500 m
Satellite		
Output losses	2 dB	0 to 2 dB
Transmitting antenna gain	44.4 dBi	38.4 to 47.4 dBi
Service contour (referred to beam centre)	-3 dB	-3 to -1 dB

One particular parameter, the antenna noise temperature, is itself a complicated function of the attenuation in the atmosphere. This function is developed in the Appendix and Fig. 1 shows the results. These results are used, together with the appropriate slant path attenuation derived from CCIR Report 564-3[7]*, in the derivation of the necessary transmitter power on board the satellite.

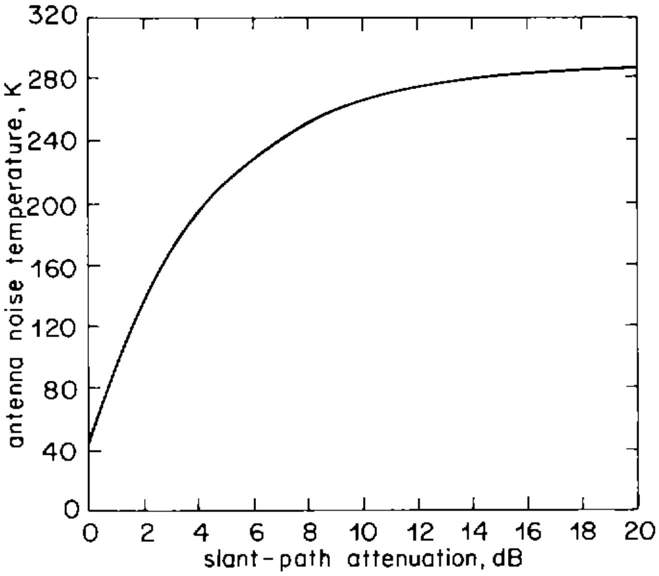

Fig. 1 - Effect of slant-path attenuation on antenna noise temperature.

The effects on the link budget (and hence the required satellite transmitter power) of varying the following parameters were calculated:

1. Noise figure of the receiver.
2. Slant-path attenuation.
3. Required carrier-to-noise ratio.
4. Frequency of operation.
5. Relative longitude of the satellite (with respect to the centre of the service area).
6. Height of receiver above sea level (a.s.l.).
7. Gain of the satellite transmitting antenna.

Having assessed the results of these calculations, realistic values of the parameters were selected which demonstrate that favourable, realistic link budgets can be obtained at 20 GHz. The parameters used are listed in Table 2. A number of comparable examples for different countries were calculated.

Table 2: Optimised Link budget parameters at 20 GHz

Operational frequency	20 GHz
Noise bandwidth	50 MHz
Antenna diameter	0.9 m
Aperture efficiency	65 %
Noise figure	1.8 dB
Dissipative loss in receiver	0.5 dB
Non-dissipative loss in receiver	0.5 dB
Antenna noise temperature	as in Fig. 1
Satellite loss	1 dB
Relative longitude of satellite	0 degrees
Edge of service contour	-1 dB
Water vapour density	7.5 g/m^3

The appropriate CCIR rain zone is used. All results are calculated at sea level except for Zaire which is calculated for 500 m above sea level.

4. RESULTS OF CALCULATIONS

The base-line example makes pessimistic assumptions about parameter values and considers operation at 22.5 GHz. Fig. 2 shows that the transmitter power increases rapidly as the permissible outage time is reduced. For example a temperate country would require a satellite power of the order 600 W to maintain a carrier-to-noise ratio of 14 dB for 99% of the year. A tropical country would require a power of about 10 kW for the same result. On this basis, HDTV at 22.5 GHz would not be available world wide and so the proposals may not receive favourable reception. It is thus desirable to examine other options.

Fig. 3 shows how the transmitter power is a function of desirable carrier-to-noise ratio. There is a direct linear relationship between these two variables.

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*It should be noted that the attenuation calculated using this method is thought[7] to be pessimistic in high rain zone climates in low latitudes.

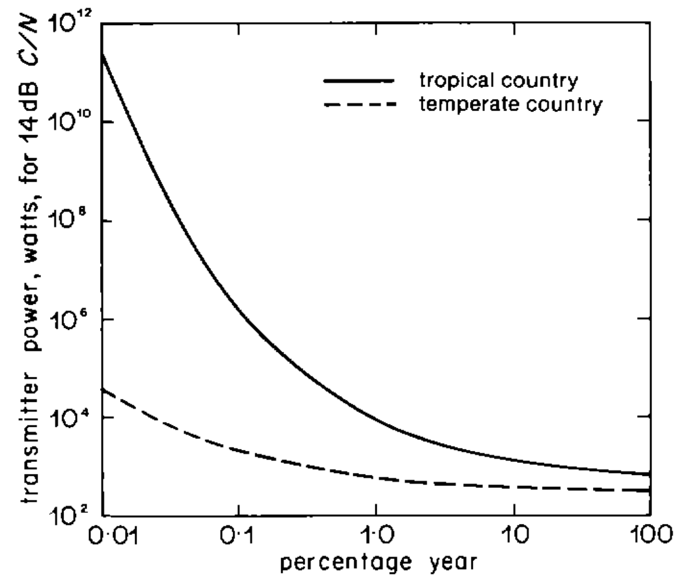

Fig. 2 - Introductory example: the transmitter power required to ensure the carrier-to-noise ratio does not fall below 14 dB for more than the stated percentage of the year using the base-line assumptions.

However the outage time depends critically on the carrier-to-noise ratio. It is highly desirable to use a system which will work over a wide range of carrier-to-noise ratios, thus minimising outage times.

Fig. 4 shows the effect of operating at different frequencies. The higher the frequency, the greater the power necessary to maintain the service. This is because the attenuation due to rain increases with increasing frequency. There is also a peak of atmospheric absorption at about 22.5 GHz. However this is small compared with the attenuation due to rain. Atmospheric (gaseous) attenuation would only be significant in relatively low rainfall zones and even then only if a service of less than 99 % of the year is being considered (see Fig. 4a).

Fig. 6 shows the effects of improving the noise figure of the receiver. Two estimates of noise figure are shown in Fig. 5. The higher curve shows figures believed achievable now. The lower curve is an estimate of the noise figures which may be achieved over the next twenty years or so. Fig. 6 shows that there is some improvement as the noise figure is improved. However the antenna noise temperature has a component which increases as the rain attenuation increases. Thus any calculations based on performance at times of high rainfall will show that it is not possible to realise all the benefits of reduced noise figure in the receiver.

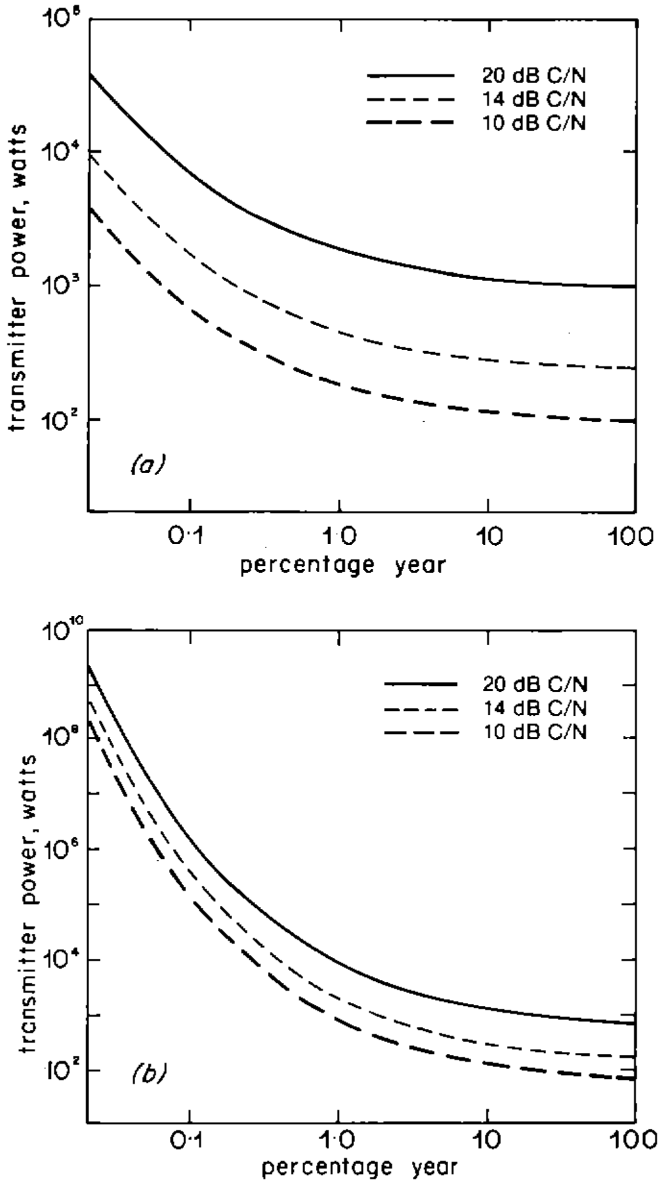

Fig. 3 - Influence of carrier-to-noise ratio: the effect on necessary transmitter power of modifying the required signal quality.

(a) temperate country *(b) tropical country*

Fig. 7 shows the effect of moving the satellite. Most proposals have considered a satellite placed somewhat to the west of the target area. This is to ensure that when the satellite goes into eclipse (and therefore loses power from its solar cells), the shutdown occurs in the early hours of the morning rather than around midnight, which would otherwise be the case. Moving the satellite to the same longitude as the service area reduces the slant path attenuation caused by rainfall. Fig. 7(b) shows that at some of the higher frequencies there can be an order of magnitude difference in power requirements. This figure also shows that there is little change in power requirement as the position moves out to about fifteen degrees west of the service area. Thus there is some control of eclipse times consistent with minimum satellite power requirements. In addition it is now thought that satellites with batteries for built-in eclipse protection are feasible, even with transponder powers of several hundred watts. Even if batteries are not used there

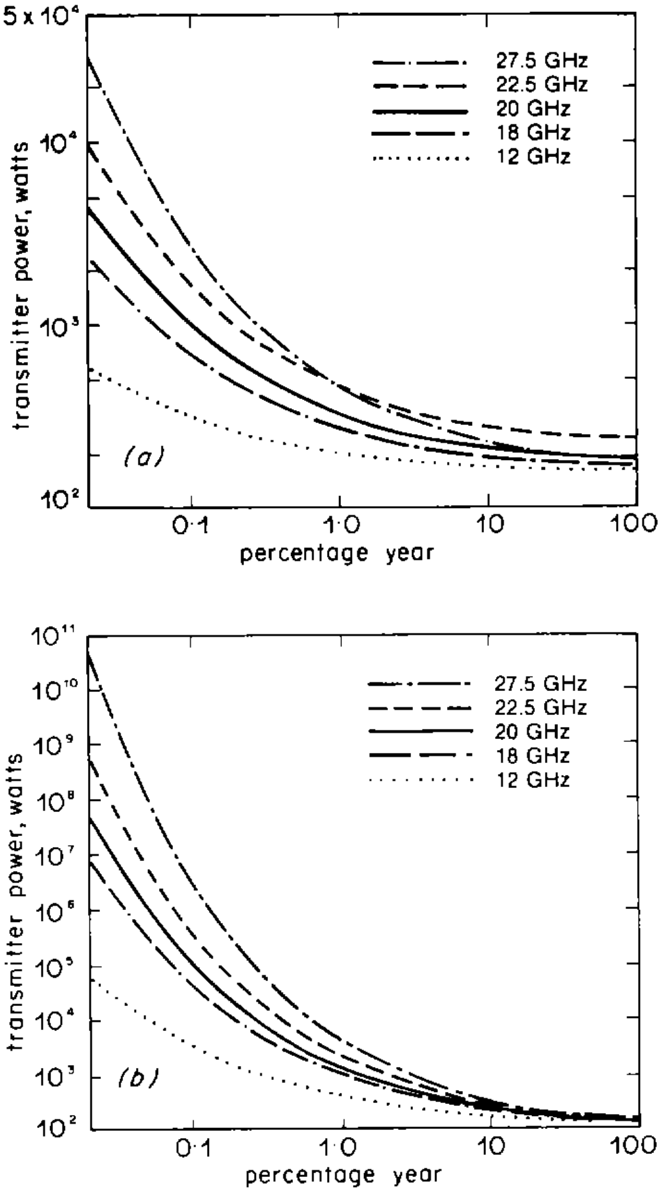

Fig. 4 - Influence of frequency: the effect on necessary transmitter power of operating at different frequencies.
(a) temperate country (b) tropical country

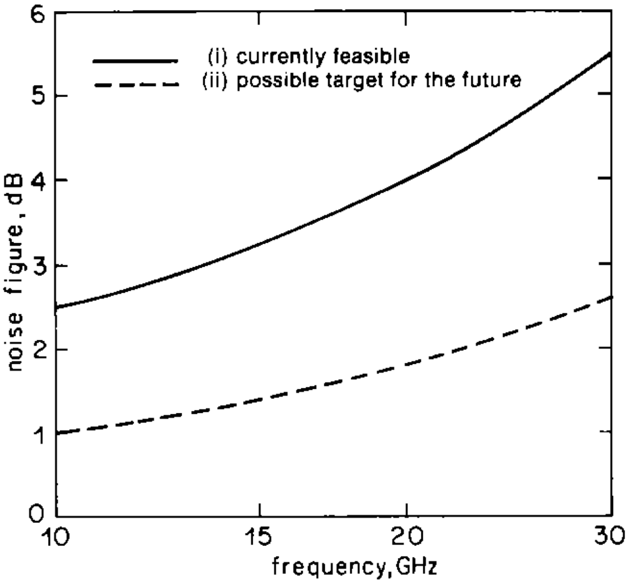

Fig. 5 - Noise figure estimates

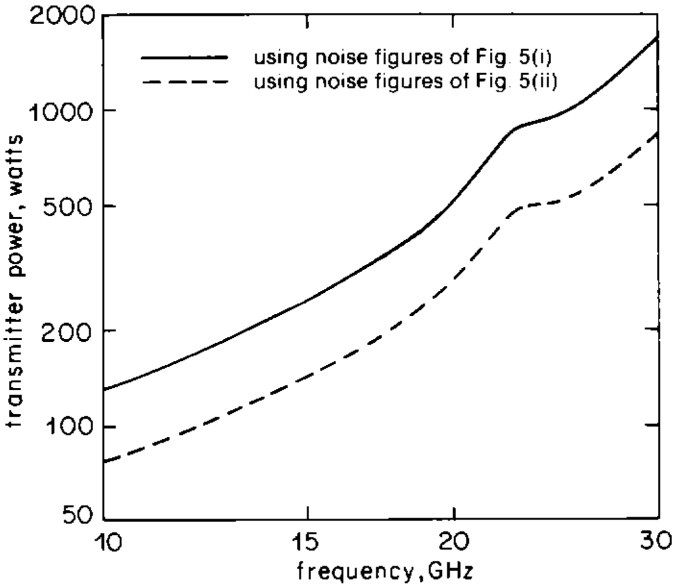

Fig. 6 - Influence of noise figure: the effect on the necessary transmitter power of improving the noise figure

may be some merit in reducing the probability of outage caused by rain fades at the expense of a predictable (and hence scheduled) shut down during the eclipse. This question needs further discussion.

Fig. 8 shows the effect of height above sea level. There are some countries which are mostly well above sea level. The CCIR rain model assumes that the attenuation due to rain is lower if the receiver is above sea level. Allowing for this in the calculations can produce a useful lowering in the necessary transmitter power.

Fig. 9 shows the influence of beam size. Reducing the size of the beam (and hence increasing the gain of the system) reduces the necessary transmitter power. Sub-national beams may be more readily engineered than national or continental beams.

Fig. 10 shows some revised examples, using the parameters listed in Table 2. Comparing these curves with those of Fig. 2, shows that by modifying the parameters which go to make up the link budget — each one by only a small and realistic amount — there is a marked reduction in required transmitter power.

As an example it is possible to consider the performance of a system based on a 100 W amplifier feeding an antenna of 1% beamwidth (and allowing 1 dB for losses). Table 3 gives an indication of the performance of such a system for several countries — these are chosen to illustrate a typical range of propagation characteristics.

The examples of Fig. 10 are all based on operation at 20 GHz.

Operation in the 22.5 GHz band may be a possibility if the band currently available in ITU Regions 2 and 3 is extended to Region 1.

Fig. 11 repeats the calculation of Fig. 10 but using 23 GHz as the operating frequency. It can be seen that a service would still be possible, but that outage times would increase marginally for the same transmitter powers.

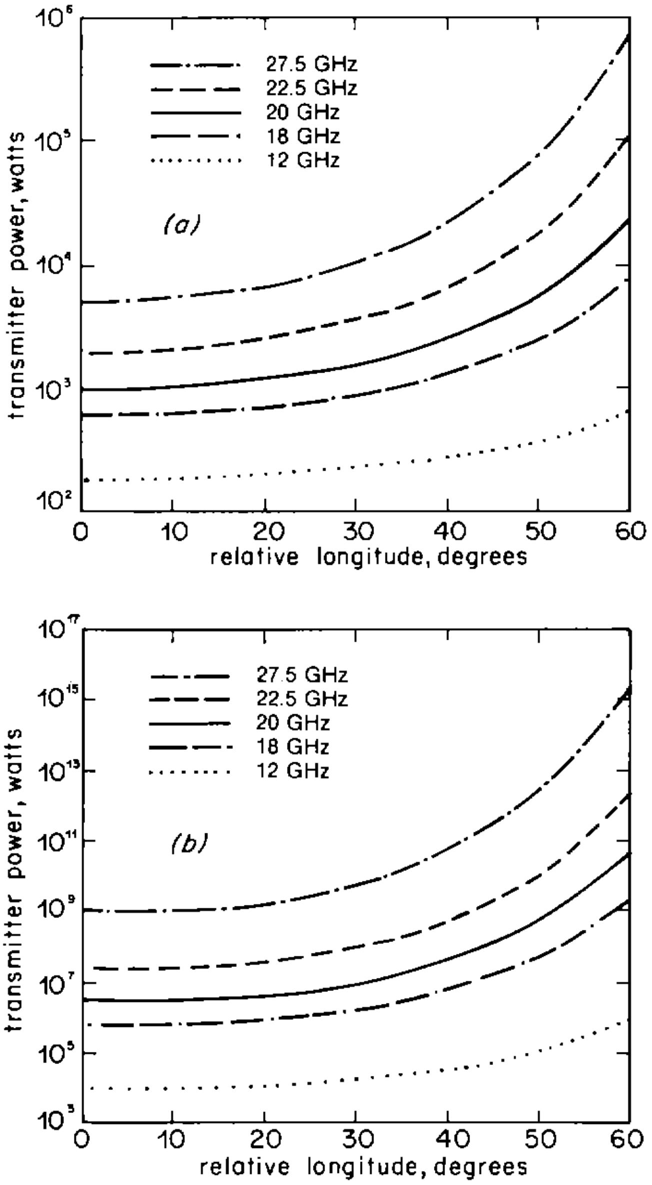

Fig. 7 - Influence of relative longitude of the satellite: the effect on the necessary transmitter power of moving the satellite's relative longitude, as a function of frequency.
(a) temperate country (b) tropical country

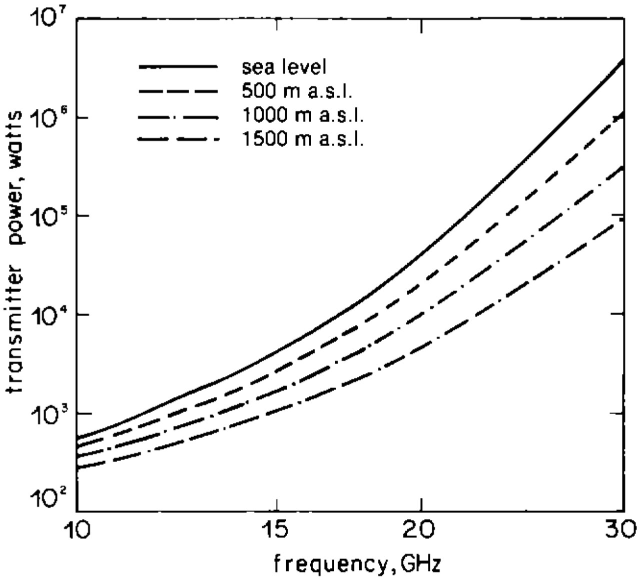

Fig. 8 - Influence of height above sea level on the necessary transmitter power

Table 3: Summary of performance for system at 20 GHz

Country	% time stated C/N ratio is exceeded		
	10 dB C/N	14 dB C/N	20 dB C/N
England	99.97	99.9	98.4
Norway	99.97	99.9	97.0
France	99.97	99.9	98.4
Italy	99.88	99.7	96.5
Algeria	99.95	99.9	98.2
Senegal	99.97	99.9	98.9
Zaire	99.60	99.1	94.0

5. CONCLUSIONS

The Report shows that the transmitter power necessary on board a satellite depends critically on the assumptions made when drawing up the link budget. The consequent range of required transmitter power in turn determines the feasibility of HDTV broadcasting by satellite. So it is essential to ensure that the link budget is optimised.

In particular, careful attention must be paid to the question of trade-off between signal quality (C/N) and the time that this is achieved or exceeded. Different trade-offs may be appropriate in different rain zones. Even so, making the simple assumption that equal powers and beam sizes are used for all service areas, gives a remarkably similar quality of service.

It is important to recognize the potential for improvements in technology. For example the possibility of eclipse protection and smaller beams for sub-national coverage can be included in the study, leading to attractive systems for even those countries in areas of high rainfall.

This study shows that favourable link budgets can be drawn up which give the possibility of HDTV at frequencies in the region of 23 GHz and above, including tropical, high-rain-zone countries. The resulting budgets are of course more attractive in temperate zones, but not unduly so.

Operation at frequencies below 22.5 GHz will lead to more favourable operational conditions. (20 GHz was used as an example because frequencies here are already allocated to the fixed satellite service).

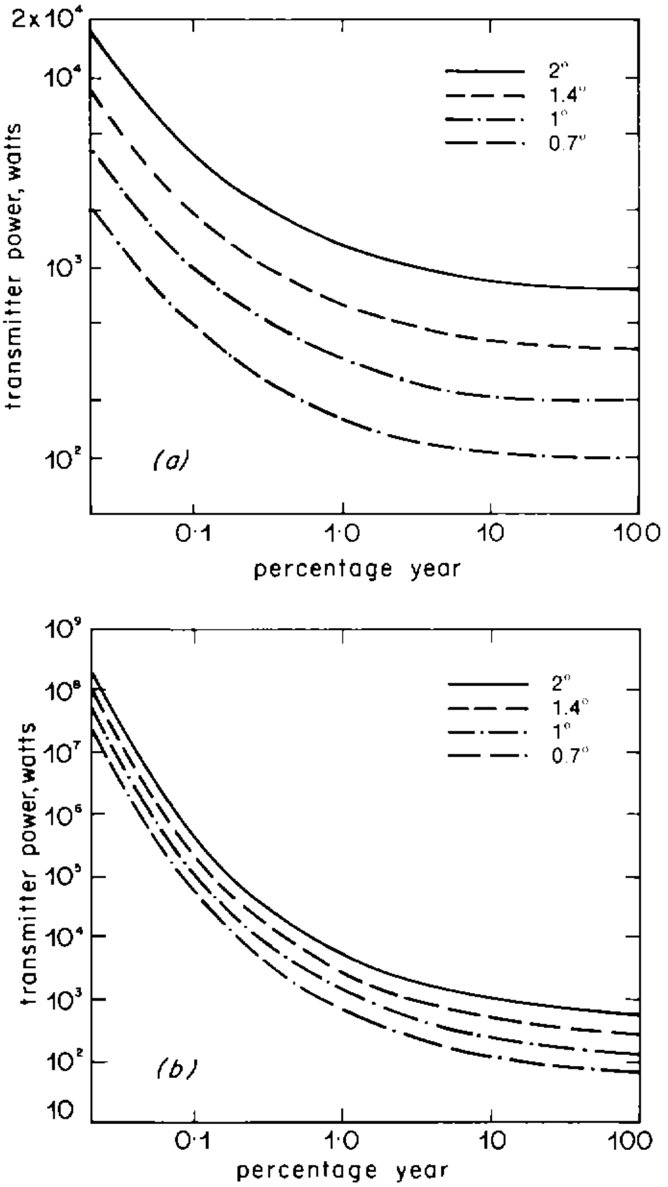

Fig. 9 - Influence of beam size: the transmitter power required to ensure that the carrier-to-noise ratio does not fall below 14 dB for more than the stated percentage of the year for circular beams of various diameters.
(a) temperate country *(b) tropical country*

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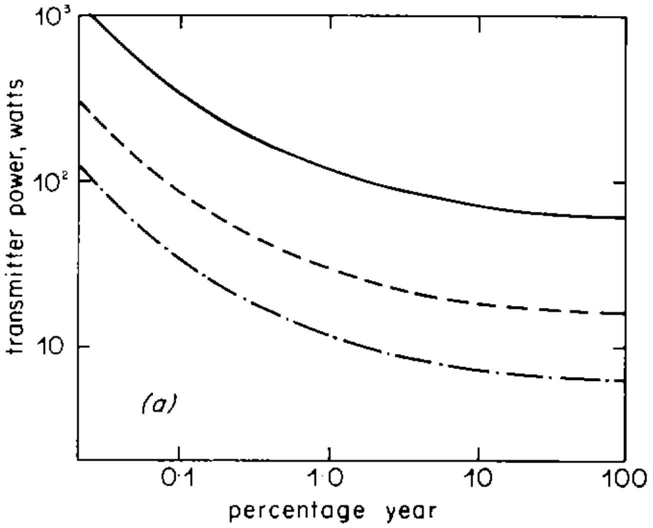

(Fig. 10a)

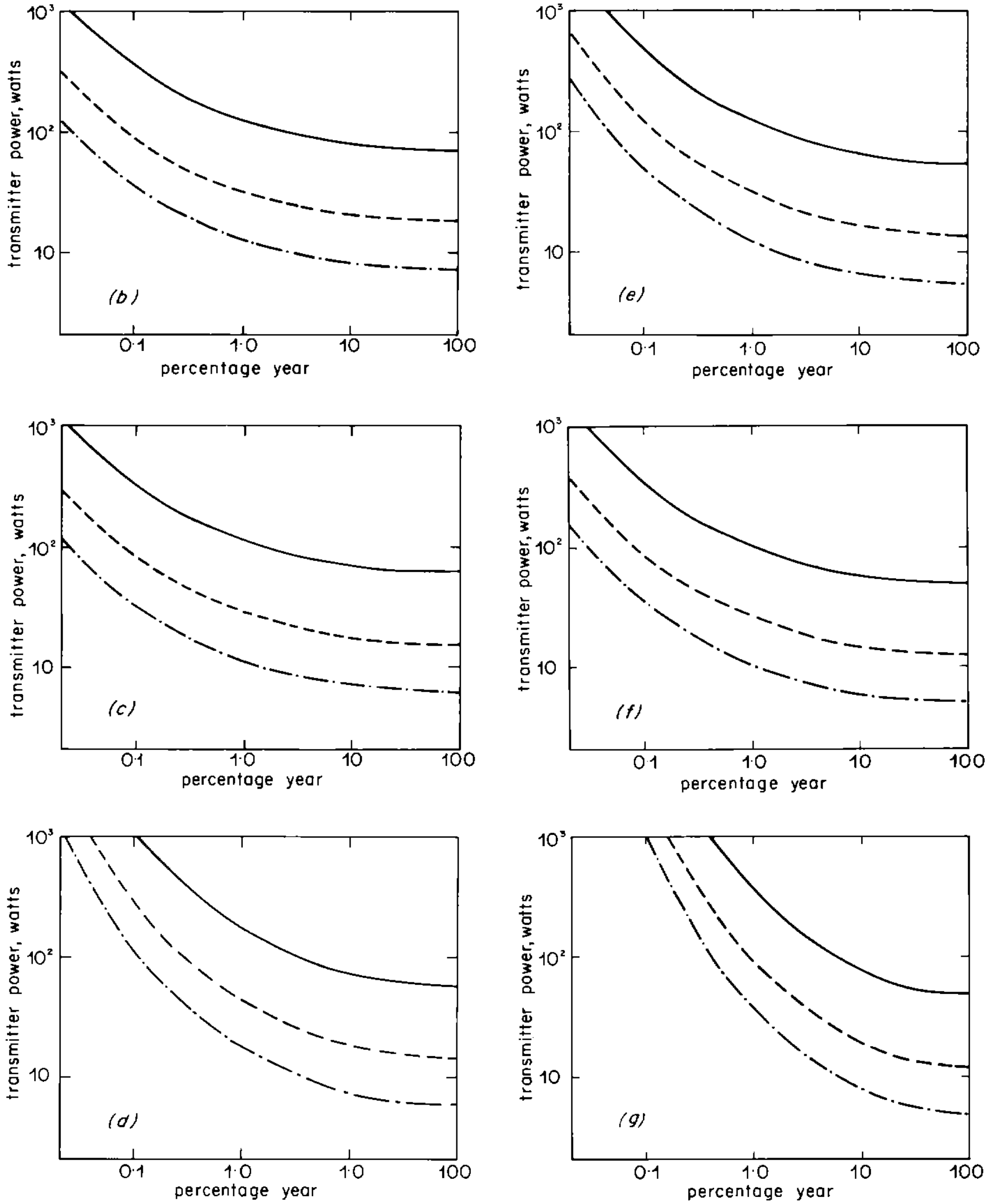

Fig. 10 - Revised examples: the transmitter power required to ensure that the carrier-to-noise ratio does not fall below the stated level for more than the stated percentage of the year. The revised assumptions are given in Table 2. Operation is at 20 GHz. (a) UK (b) Norway (c) France (d) Italy (e) Algeria (f) Senegal (g) Zaire

——— 20 dB C/N
– – – – 14 dB C/N
—·— 10 dB C/N

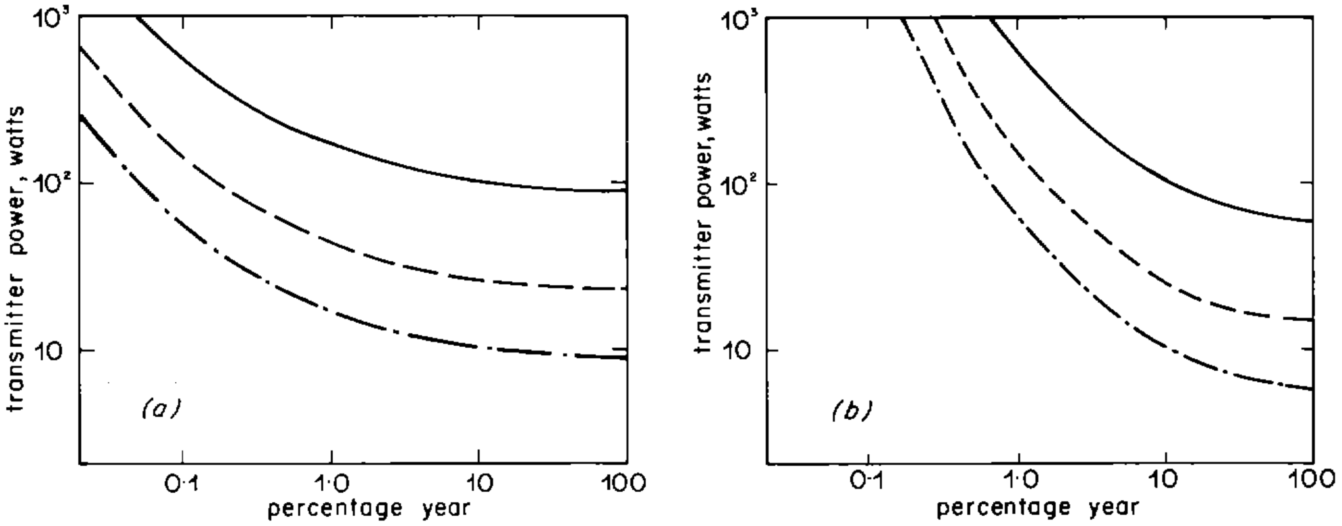

Fig. 11 - Revised examples: the transmitter power required to ensure that the carrier-to-noise ratio does not fall below the stated level for more than the stated percentage of the year. Operation at 23 GHz but otherwise as detailed in Table 2.
(a) UK (b) Zaire

——— 20 dB C/N
— — — 14 dB C/N
—·— 10 dB C/N

APPENDIX

Effect of slant-path attenuation on antenna noise temperature

It is assumed that the mainlobe and nearby sidelobes (out to 19° off axis) account for 0.7 of the power response of the receiving-antenna radiation pattern. This is approximately true for the WARC-77 receiving-antenna template. The mainlobe and nearby sidelobes are assumed to give a contribution to the total noise temperature at the effective sky-noise temperature T_S, and the remainder to contribute one-half at T_S and one-half at ground noise temperature T_G.

Then $T_S = T_B A + (1 - A)\, T_O$

where T_B is the cold-sky cosmic background temperature = 3 K

A is the slant-path attenuation, expressed as a fractional ratio

and T_O is the effective temperature of the lossy medium, assumed equal to 290 K. This value is also assumed for T_G.

Thus the antenna noise temperature T_A is given by

$$T_A = 0.7T_S + 0.3\,(T_S + T_G)/2$$

$$= 0.7T_S + 0.3\,(T_S + T_O)/2 \qquad \text{(if } T_G \text{ is assumed equal to } T_O\text{)}$$

$$= 0.85T_S + 0.15T_O$$

$$= 0.85\,(3A + (1 - A)\,T_O) + 0.15T_O$$

$$= T_O + A\,(2.55 - 0.85T_O)$$

$$= 290 - 244A\ \text{(K)}$$

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